THE CENTRAL AND PERIPHERAL VISUAL ACUITY OF THE LIGHT-ADAPTED AND DARK-ADAPTED EYE

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16. Abstract

Light-adapted vision is sharper and fatigues less. The effect of peripheral angles of vision is determined.

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THE CENTRAL AND PERIPHERAL VISUAL ACUITY OF THE LIGHT-ADAPTED AND DARK-ADAPTED EYE

Edwin W. Katzenellenbogen

Even ordinary observation teaches us that vision with the lateral portions of the retina is very important, and actually essential, for orientation in space. Aubert mentions, among others, the experiment by Purkinje, which shows that if vision is limited by a diaphragm to just the position of the macula lutea, one cannot even orient oneself in one's own room [1]. Thus the indirect vision also has an important clinical significance. Although the ophthalmologists usually feel it their duty to test only the central visual acuity in study of visual acuity, the only good reason for that is that the study of the peripheral visual acuity encounters great difficulties and requires particularly great experience and much expenditure of time. /272*

The physiologists and psychologists have approached the problem more closely, and many works have been concerned with testing the acuity and accuracy of spacial distinctions in indirect vision, along with study of light and color perception. But the problem is by no means completely solved. With respect to indirect vision in dark adaptation, in particular, the results differ so greatly that a new study seemed desirable. In the winter semester of 1902/1903, Privy Councilor Wundt transferred to me the continuation of such a study, which

* Numbers in the margin indicate pagination in the original foreign text.

late Dr. Savescu (1) had started. I completed it at the Leipzig Physiological Laboratory in the course of three semesters, in which I studied primarily the visual acuity of dark adaptation. I did not neglect including light adaptation also in my experiments. The experiments were done with light objects on a dark background with the objective light intensity constant. Only occasionally did I study the visual acuity with the brightness reduced to subjective equality. I also limited myself to the use of two parallel lines immediately adjacent (more detail below) and in only one case did I concern myself with the so-called Wülfing experiment, in which a single broken line indicates a measure of visual acuity. I reserve the extensive treatment of this problem, as well as a study of the visual acuity for different colors, for a later work. /273

Before coming to the theme proper, I wish first to thank my honored teacher, Privy Councilor Professor Wundt for the stimulation to this study and for the abundant support of the study. I also thank Prof. Wirth, Assistant of the Institute, for the trouble in making the apparatus and for much advice. The visual acuity apparatus was admirably produced in the shop of the mechanic, E. Zimmermann, in Leipzig.

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(1) Dr. Gusti has kindly translated from Rumanian the published notes of our colleague, who unfortunately died so early. As they were written disconnectedly, I had to begin the study anew, especially as the apparatus available to Dr. Savescu had to be improved. See the description of the apparatus.

(2) Wülfing, Zeitschrift für Biologie, 1893, p. 199 (a quite brief report): Study of the smallest perceptible visual angle. Other works on this subject: Volkmann, Optical Studies, I. Hering, Sitzungsb. d. sächs. Ges. d. Wiss. Mathem.-phys. A. 1899. See also Wundt, Physiological Psychology, Vol. II, 5 A. P. 505.

The test subjects were Prof. Dr. Wirth, Dr. Krüger, Dr. Lipps, Dr. Tsukahara of Tokyo, S. Loria of Cracow, and J. Reiss of Czernowitz.[1] I thank all these gentlemen, and especially my dear friend J. Reiss, who devoted more than two hours day after day for three semesters to this difficult and very tiring work. / 274

Apparatus and Experimental Arrangement

Methods. In practice, the test of visual acuity is usually done with Snell or Jäger reading samples. But Purkinje, Volkman, Aubert and others [2] have already attempted to test the visual acuity by direct determination of the space perception threshold. This can be determined for the spatial study with two light points, in analogy with the divider test of E. H. Weber for the sense of touch.

The first of the methods mentioned for study of the visual acuity, the reading sample method, is seriously affected by various side effects with disturb the investigation. Here the test subject determines whether or not he sees a letter (usually a printed E) clearly. Accordingly, if a letter seems blurred, he says "indistinct". This makes the determination of the limit significantly higher. On the other hand, the associative process and remembered images from reading have a not insignificant effect on the judgement to be made, so that a letter can very easily be recognized as such even if it is objectively defective. I can remember that in the testing of

(1) I myself could act only very inadequately as observer. My left eye is quite astigmatic, and in the course of the study my right eye was affected by an eye disease. With respect to the observation material, then, I referred entirely to the reports of others. Most of the curves and tables are based on the observations of Mr. Reiss. Other test subjects served only as controls.

(2) See Aubert, loc. cit., p. 236.

my sight, the same Snell table was always held up, so that finally I knew the series of letters almost by memory. After some time I was able to read the lowest row easily. This seemed very improbable and in fact, when another table, for which I /275
did not know the letters, was presented, I could not even read the fourth row from the bottom. It is also generally known that an inscription which one cannot at first detect from a distance, and then has deciphered through a telescope, then seems to be easily readable with the naked eye.

The ophthalmologist cannot, of course, avoid this situation as a source of error, so that they prefer the vision tests otherwise considered only for illiterates. Here the patient is supposed only to indicate the difference in directions of straight lines. In the scientific studies also, one attempts to avoid that error. For instance, Köster and Fick used hooks with the form ⊏. This reduced the error, of course, but did not completely eliminate it.

<u>The Space Perception Threshold Method</u>. In comparison, the errors just mentioned vanish with the space perception threshold method. This requires the test subject to state whether he sees one or two lines or points. It is fairly immaterial whether this impression is distinct or "blurred". The disturbances are caused partially from the irradiation of the light, and partly through inadequate accomodation. To be sure, accomodation has a certain effect even here, as everywhere. But the elements of the presentation are significantly simpler, so that this factor cannot have such manifold effect on the observation. Therefore, the space perception threshold method would also be worth recommending for clinical investigation (1). It is a postulate for any scientific work in this field.

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(1) This opinion has actually been accepted at many clinics (in Berlin, for instance).

The space threshold perception study of the sense of touch has proved itself particularly in the diagnosis of nervous disturbances, and has received wide acceptance. From what has been said, then, it will be obvious that the following investigation used the space perception threshold method exclusively to study visual acuity.

To be sure, this method also has many problems, especially in dark adaptation. While, with light adaptation, two dark lines may be presented on a white background, or two white ones on a black background, in reflected light, with dark /276 adaptation it is simplest to use lighted stimuli. But this situation causes great difficulties. Aubert (1) illuminated wires with an electric spark from the discharge of a Leyden jar. But the error of this sort of illumination is in the brevity of the experiment. On the other hand, it certainly eliminates the effect of deviation from the point of fixation. Through its suddenness and brightness the stimulus has such a startling effect on the observer that he is not as perceptive and reduces his judgement to chance. Therefore we initially used platinum wires which themselves could be made to glow by a constant electrical current. Thus, from the beginning, we took care for the longer stimuli. The observation in indirect vision is extremely difficult because we are accustomed to fixing on the light stimulus which we want to perceive. By practice, we are able to free ourselves somewhat from that, so that we can hold a fixation point, especially if we are fixed on it from the beginning and are given a preliminary signal (2). But small, even momentary variations in the direction of sight cannot be avoided. Under some circumstances they can completely distort judgement. In order to prevent this, on the suggestion

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(1) Aubert, Physiology of the Retina, p. 237.

(2) See under Experimental Arrangement.

of Privy Councilor Wundt, we always presented simultaneously a nasal and a temporal stimulus, so that the tendencies to involuntary deviation of fixation would remain in equilibrium, so to speak. There were many technical problems with the glowing platinum wires. The rise in light intensity is slow, and the color varies. This circumstance is not without effect on adaptation. The spread of the light and the dazzling is very great, so that I could not obtain useful and reliable results in studying visual acuity with glowing wires. Thus, we constructed an apparatus which almost entirely avoids the error just described, while retaining the principle.

The Apparatus

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In the description of the apparatus, we shall present only the specific features and their advantages. Otherwise, the reader should refer to the schematic drawing (Figure 1).

The apparatus is conceived on the principle of a perimeter. But in place of the arc, a straight rod a meter long, divided in centimeters (1) is attached. It can be rotated about the point of fixation. It is mounted to the table by inserting a round rod holding the entire apparatus into the hollow clamp. According to the principle of symmetric stimulation described above, a double-line device of completely symmetrical design is now attached at both sides of the point of fixation. In the new apparatus the lines are obtained by slots of transparent ground glass at the edges of small light-tight boxes. Incandescent electrical lamps of 36 candlepower at 110 volts are mounted in black boxes (C) (E: open view of the interior of the box). The movable slots (n) can be varied from the finest line of light to a broad band. Ground glass plates are placed behind them to get diffuse illumination. The edges of

(1) This centimeter division can also be noted in the dark because small holes are placed 2 cm apart. Spring-loaded projections from the boxes snap into them.

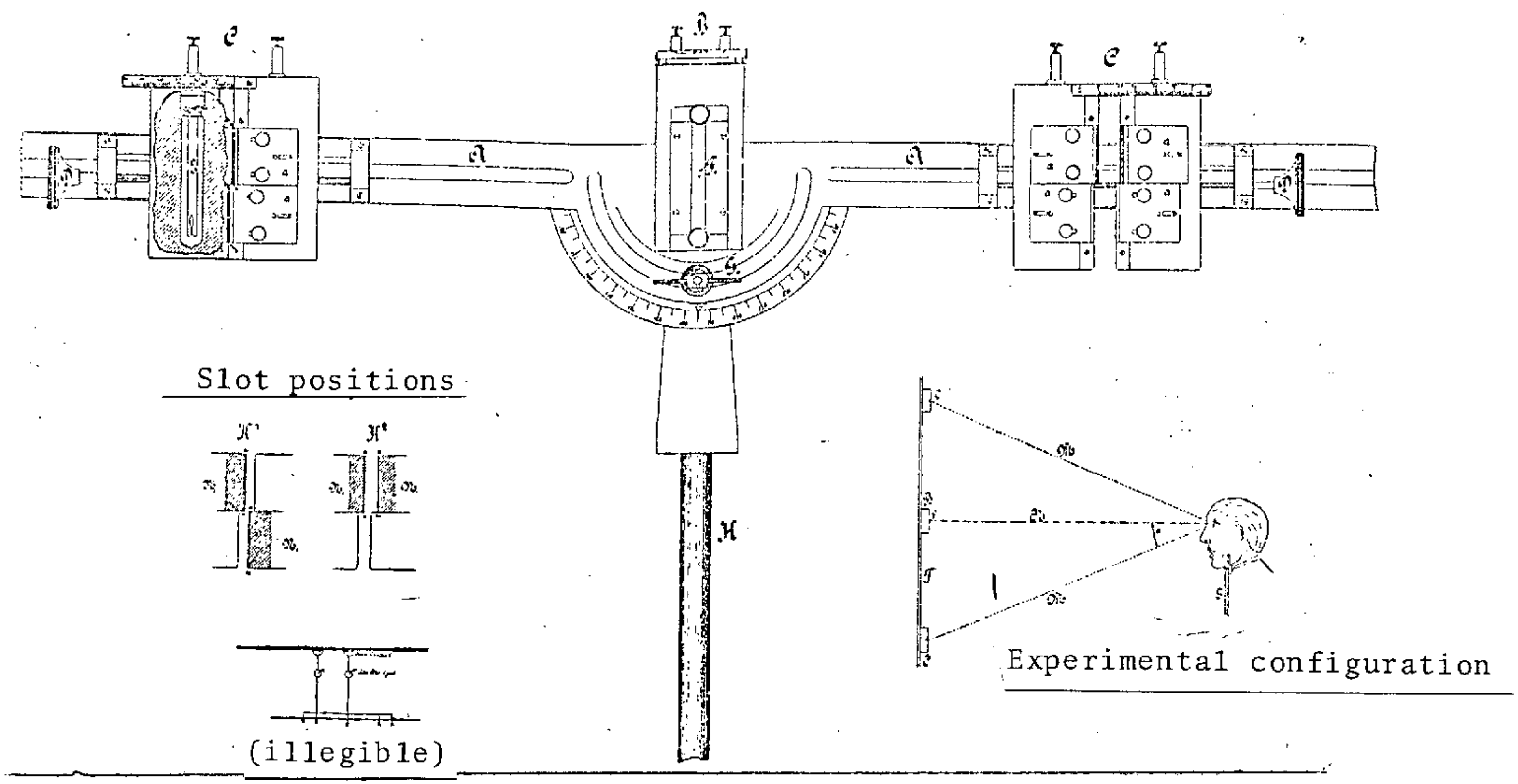

Figure 1. The apparatus.

the slots are polished at the front and lie directly on the ground glass so that the perception of the bright lines from the side is not hindered. The drawing K_2 shows the slit arrangement most clearly. With a micrometer screw (D), one moves the boxes apart. The distance is read directly in millimeters from the scale at the top. Drawing K_1 shows the use of the slits for the so-called Wülfing experiment. Here a broken line is taken as a scale for visual acuity, with one half of the line moved with respect to the other. With this apparatus the broken line appears because the upper part of the right and the lower part of the left box are cut more /279 deeply, so that the upper left edge of one stands above the lower right of the other. From this position they can be moved by the micrometer screw (D).

An electrical lamp in the box (B) also serves to illuminate the transparent fixation point (F). The fixation slit can be covered by sticking on a black piece of paper. Then one can make an arbitrarily dark fixation mark with a more or less deep needle puncture. The electrical switching diagram presented with the conventional symbols shows that the fixation point is independently illuminated and darkened. Furthermore, only one of the double lines can be provided as an objective unit. (This can also be obtained by closing one slot entirely). The electric line of 110 Volts was used as the power source (1).

(1) The objection might be raised that I had no special control of the current. It is natural for the current to vary, depending on the usage. But, first, I worked at fixed hours, predominantly between 2 and 5 in the afternoon, with the same observers. Within this period the times for the individual positions for the retina were often changed. In order to keep the lamp brightness constant, I changed all the lamps for new ones every four weeks. In particular, though, the experiment with change of the light intensity (screening by episkotister*) presented below showed the minor effect of brightness differences within the limits applying here for the problem of visual acuity.

*Translator's note: This is an unknown old German word.

The bar (A) can be turned 90 degrees to the right and to the left about its axis, 180 degrees in all (screw G and degree division with pointer). This makes it possible to study visual acuity in all possible meridians. The apparatus is made completely symmetrical, greatly improving the stability at any setting.

So that the lines will be exactly vertical at any meridian, the entire double-line system can be rotated on the plate which moves along rod A, and it has a level on the top. For adjustment, the plate is clamped solidly by a bolt to rod A. In order to help exact fixation, the head of the observer rests on a chin rest, as indicated by the /280
schematic drawing of the experimental arrangement.

The results are reported in visual angles. The calculation is based on the formula: $\log \tan \alpha = \log a - \log h$ (in the drawing $h = N$, $a = T$). Here $h = N$ is the distance of the eye from the point of fixation; $a = T$ is the mean distance of the two lines from the point of fixation. The N distance was usually held constant at 3 m. I have convinced (1)
myself that the accomodation conditions are most favorable at this distance. The distance was reduced to ½ m only for visual angles greater than 30 degrees, and extended to 7 m for study of the central and paracentral visual acuity.[2]

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(1) I satisfied myself that the problems from "blur" were rarest here with non-myopic eyes. The myopic observers wear compensating glasses.

(2) The difference in the distance was due to the technical impossibility of going beyond 40 degrees at 3 m distance. At small distances, the variations would have to be millimeters, and that, of course, would be difficult to do under these conditions.

Operation of the apparatus is entirely simple and convenient, and line power can be used. This makes it possible to use the apparatus clinically when it is desirable to have an accurate statement of the visual acuity and not just to find the number designation for the glasses to be worn.

The Experimental Arrangement

a) With dark adaptation. The room in which I worked was completely light-tight. The observer had one eye shielded. The other eye was dark-adapted for at least 20 minutes before the beginning of each study. After the observer had rested his head on the chin support and said "now", the experimenter switched the center lamp on so that the lighted fixation point appeared. The observer now sought to fixate exactly. After his "yes" the left and right stimuli, both at the same distance from the fixation point, were shown simultaneously. The entire experiment lasted from 4 to 2½ seconds, depending on the practice of the subject. One could not observe accurately / 281
below this time, especially if the position was very eccentric. At times more than 4 seconds, fixation was impossible without significant deviations. During operations on the apparatus, the test subject always shielded his eye from any incident light by holding a black cloth in front of it. Enough time was allowed between the individual experiments for regeneration of the adaptation and for the complete decay of the afterimages.

In the study of the central visual acuity in dark adaptation, the fixation point was presented immediately before the experiment and turned off during the experiment. It was supposed to indicate the direction of the expected stimulus. Points were used instead of lines, so that only the fovea was affected.

b) With light adaptation. Naturally, the testing of visual acuity with full light adaptation had to be done with brighter light. Although I wished to experiment with light which was just as strong, objectively, as with dark adaptation, I could not do this with full daylight, and could work only with reduced illumination. Therefore I worked at strong twilight or with illumination of 16 candles from 3 incandescent lamps. The arrangement seemed adequate to me because this series of experiments served only for comparison. Here, again, points rather than lines were used in testing the center.

The left eye was always used in the observation. The right eye was used only for comparison.

The Method

The experiments were performed with the method of minimal changes. This method appeared most suitable for the nature of the experiment. I carried it out quite consistently, by proceeding from distinct one-ness to clear two-ness and back the same way. Only the means of the results were used for the calculation. But as much as possible, I avoided excessively small steps, first because this was very tiring for the test subject, and also because it would have made it impossible to to the entire series of experiments in one sitting, which is of greatest importance. With many test subjects, Dr. Ts., /282 for example, there was a notable influence depending on whether the series of tests was started with definite one-ness or two-ness. At an eccentric part of the retina (8°) this observer believed he saw two-ness clear up to objective one-ness if I started the test with two-ness, and vice-versa. I repeated the test 3 times on different days and always got the same result. As Dr. Ts. also had eye trouble, this may be ascribed to the pathological condition of the retina.

In the many previous works on the space perception threshold, one generally finds the one-ness and two-ness curves for the different retinal positions plotted with the matching numbers. The uncertainty curves, in contrast, are never reported. Uncertain judgements are usually reported unsystematically, occasionally in parentheses, or with a question mark, and considered as errors of attention or of the experiment. They have usually been ascribed half to the oness judgement and half to the two-ness judgements. It is also believed that they can be eliminated through practice.

Now I noted with many test subjects that there was a certain hesitation in testing various points on the retina if they were required to decide whether they saw one or two lines. They hesitated as to what they should actually report having seen. I concluded, therefore, that I would leave the test subjects greater room for play in their judgements. It turned out, then, that about 6 distinctions gradually appeared: definite one-ness, one wide, one uncertain, quite uncertain, 2 uncertain, definite two-ness. If we ignore the distinction between 1 and 1 wide (1), 5 distinctions remain. Therefore I undertook a more detailed study of these doubtful cases, and soon noted that these not only did not decrease or disappear with time, i. e., with practice, but, on the contrary, increased at the expense of the uncertain one-ness and two-ness. The certain judgements also became enriched at the cost of the uncertain one- and two-judgements, so that in fact, these appeared more and more seldom with longer practice, and finally three sharply differentiated distinctions emerged: one-ness, uncertainty, two-ness. The rare judgements of the uncertain 1 and 2 were /283

(1) It is another problem, which approaches that of Wülfing.

omitted in the calculation [1].

The relations can be seen in detail in the frequency curves in Figure 2. These are calculated from 500 single observations. Otherwise, the series are in general made up of 130 single observations. The following table is represented in curves I and II.

FREQUENCY TABLE CALCULATED IN PERCENT

Curve I (at 60 degrees eccentricity); test subject, Reiss, left eye, dark-adapted:

Distances between lines in minutes of arc for the visual angle	175	170	165	160	155	150	145	140	135	130	125	120	115
Certain two-ness 2	100	83	71	52	27	11	0	...	...	...	...	...	...
Uncertainty ?	0	17	29	48	73	89	100	95	68	68	44	27	0
Certain one-ness 1	...	...	...	...	...	...	0	5	32	32	56	73	100

Curve II (at 30 degrees eccentricity); test subject, Reiss, left eye, dark-adapted:

Distances between lines in minutes of arc for the visual angle	63	60	57	54	51	48	45	42	39	36
Certain two-ness 2	100	72	72	43	20	3	1	0	...	...
Uncertainty ?	0	28	28	50	50	42	44	30	25	0
Certain one-ness 1	...	...	0	7	30	55	54	70	75	100

(1) I intentionally ignored the uncertain 1 or 2 judgements. First, they reduce to a minimum after a certain practice. Second, they occur at all only in a vanishingly small number, and just at the transition points.

According to this, the two-ness curve for 60 degrees begins at a visual angle of 145' and rises rapidly to the maximum at 175'. Here the two-ness is absolutely certain. The curve / 284
for certain one-ness begins approximately at 145' also, grows rapidly, and at 115' only one line is seen. The curve of the quite uncertain judgements has, in contrast, a semicircular course. It has its maximum where the certain twoness judgement has just disappeard and the one-ness judgements are appearing. If falls off slowly to both sides from this point (145') and accompanies both the two-ness and the one-ness curves with decreasing values until it reaches zero.

Curve II shows a similar course, except that here the relations are not quite so extreme. All three judgement qualities are present on many portions (between 54' and 45'), but here the uncertainty judgement attains only an absolute majority.

These two tables are only two particularly meaningful / 285
examples of many. The regularity of the doubtful cases is apparent. One cannot merely call them errors and ignore them, but one must consider them in a special section. The curves become more regular the more eccentric the point on the retina which is studied is. Up approximately to the blind spot, on the other hand, no regularity can be established, in spite of the greatest effort. The frequency curve for central vision shows the best relative regularity:

Curve III (foveal vision, left eye); subject, Reiss; dark-adapted. Frequency in %:

Minutes of arc:	10'29"	9'	7'36"	6'12"	4'51"
Certain two-ness 2	100	40	10	2	0
Uncertainty ?	0	60	75	48	100
Certain one-ness 1	0	0	15	50	100

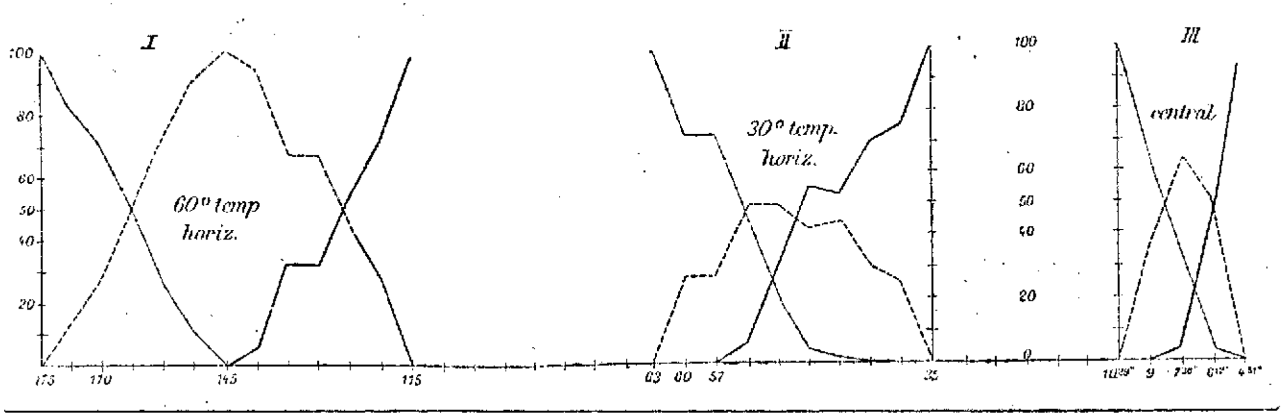

Figure 2. Dark adaptation

———	one-ness judgement	Observer:	Reiss (left eye)
– – – –	uncertain judgement	Abscissa:	frequency of judgement in %
–·–·–·–	two-ness judgement	Ordinate:	threshold in minutes.

In the study I endeavored to obtain the limiting value for certain one-ness and certain two-ness. I call the entire segment lying between the two thresholds of visual acuity and, so to speak, "visual insensitivity", the zone of uncertainty. The judgements which are well understood as such are by no means variable.

If we look at curve IV (Figure 3) we note that the region expands greatly at about 20 degrees eccentricity. One might believe that the unity judgements increase, but this is not the case. The one-ness curve actually rises significantly more slowly, in comparison to the two-ness curve. Only the zone of uncertainty expands more and more. This special fact must be emphasized. As mentioned above, it is linked with the increase of the absolute threshold and shows that not only just the threshold but all the psychophysical region of judgement (including the region of uncertainty) have a proportionality to the total cause of the increase in the threshold, sililar, for example, to the Weber law for stimulus intensity. I am certain that one could even calculate the proportionality /287 coefficient. One would only have to have more numerical material available. In the region of the sense of touch it would be considerably easier to establish this study of the "zone of uncertainty". While one can perform at most 20-30 experiments on the visual sense in one hour, at least 100 can be done with the sense of touch. I have chosen the two-ness judgements for the numerical presentation of the visual acuity. They are more closely related than the one-ness judgements to the "distinct" judgements of the reading sample method, which there indicate a measure of visual acuity.

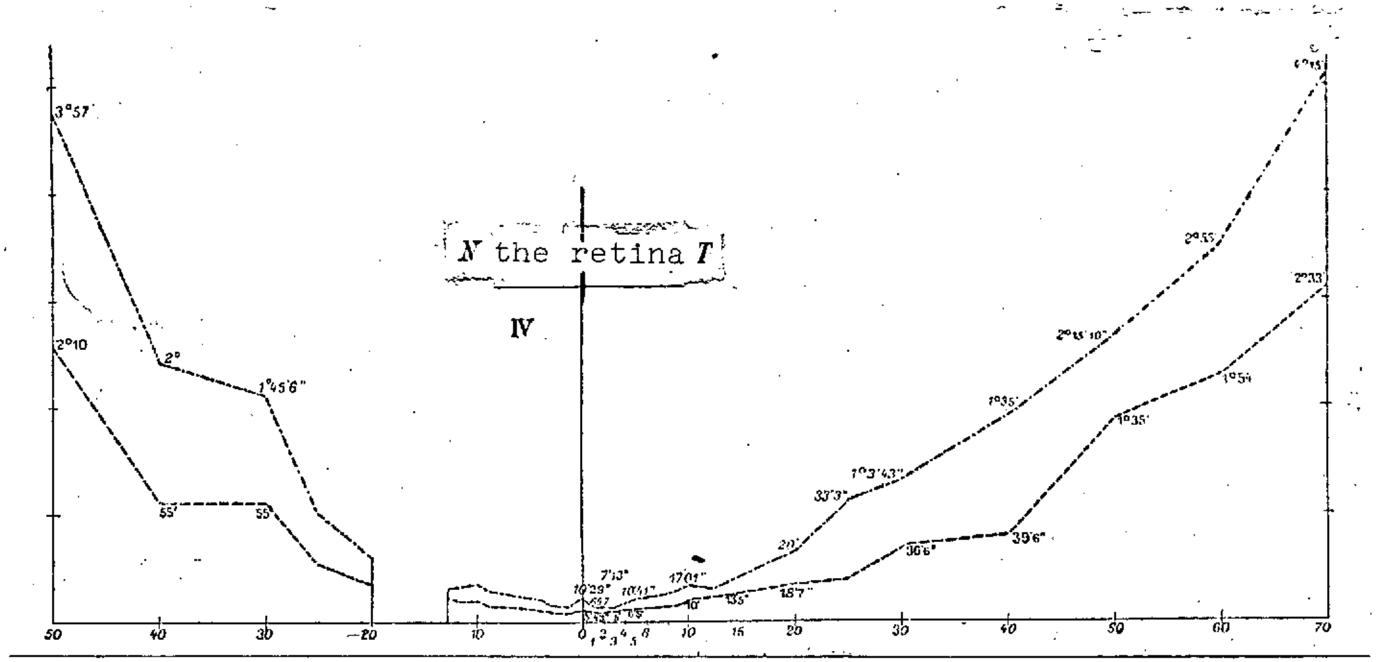

Figure 3. Course of the spatial perception threshold (expressed as the visual angle) with dark-adaptation.

—·—·— certain two-ness

– – – – certain one-ness

Observer: Reiss (left eye); horizontal meridian.

The Visual Acuity of the Dark-Adapted Eye in Comparison to the Light-Adapted Eye.

I. The visual acuity of the dark-adapted eye had considerably different magnitudes in the peripheral parts of the retina than was expected from Fick's results. At first I believed that perhaps my test subjects were incompletely adapted. Thus, I extended the pre-adaption to one hour. It turned out that in fact the eye still experienced small changes in its visual acuity after one half hour. Nevertheless, I could not obtain Fick's results. Most results, as well as all curves, refer to the horizontal meridian. They are derived from the observations of Mr. Reiss with the left eye. His right eye was rather seriously myopic, so that it had higher space perception thresholds. Otherwise, the course of the curve was almost the same. The observations from other test subjects show no significant deviations from the curve plotted in Figure 4. Only at one point does the curve of the reciprocal visual acuity at dark adaptation agree with Fick's results (1). The visual acuity of the dark-adapted macula lutea has a lower value than the immediately adjacent periphery, the so-called paracentral region, as can be seen from the following numbers: /289

Eccentricity	Visual Acuity
0°	0.49 (2)
1°	0.74
2 and 3°	0.69
4°	0.56
5°	0.46

(1) Also with the results of Bloom and Garten, Archiv f. ges. Psychologie, Vol. 22, p. 5.

(2) In order to approach the tests with reading samples more closely, I reduced the unit of visual acuity by 5, according to Snellen, making possible direct comparison of the results.

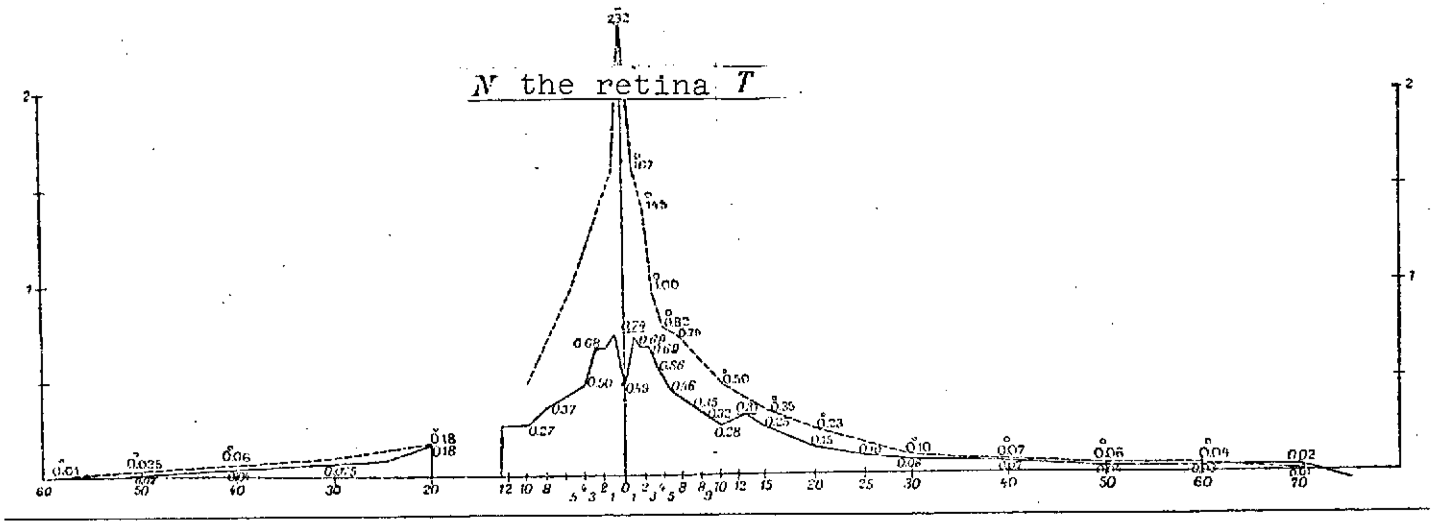

Figure 4. Curve of the visual acuity.
——— with dark adaptation
- - - - with light adaptation
Unit of visual acuity = 5 (according to Snellen).
Observer, Reiss (left eye). Horizontal meridian.

According to this, at 5 degrees the curve again reaches the visual acuity of the yellow spot. Then there is a rapid drop to 12 degrees, followed by a slower drop from 20 degrees to 70 degrees temporal (1) and up to 50 degrees nasal. Thus the dark adapted eye shows the best visual acuity between ½ degree and 1½ degree.

At 12 degrees the curve rises somewhat again, presumably because there is only one-sided response between 12 degrees and 20 degrees because of the blind spot. The test subjects were not accustomed to unilateral observation, and compensation through unsymmetric adjustment of the lamps would have introduced other complications.

Figure 3 shows the magnitudes of the one-ness and two-ness thresholds for the individual points on the retina. It was still possible to show an uncertainty curve connecting those points at which the uncertainty judgement occurred most often. But from the existing experiments I could only establish the hypothetical curve. At first it remains fairly well in the center up to 12 degrees. Then up to 30 degrees it approaches the two-ness curve. From 30 degrees to 70 degrees it runs nearer the one-ness curve.

II. The light adaptation curve (Figure 4, numbers designated by the mark °) is not really basically different, except that it is above the dark adaption curve in its entire course. Only at 70 degrees temporal is it somewhat below that curve. From 50 degrees to 70 degrees temporal it falls off somewhat more steeply. Nasally, it is much above the

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(1) I retain the physiological notation for better understanding. Temporal, then, means the temporal side, and nasal means the nasal side of the retina.

dark-adapted curve. The dark-adapted eye no longer differentiates /290 above 50 degrees, and the light-adapted eye, in contrast, still differentiates at 60 degrees. Only at 20 degrees do the two curves touch. At this point the nasal side is very superior to the temporal.

NUMERICAL MAGNITUDES OF THE VISUAL ACUITY

	nasal						central	temporal						
light-adapted	0,01	0,025	0,06	0,10	0,18	0,30	2,32	0,30	0,35	0,10	0,07	0,06	0,04	0,01
dark-adapted	—	0,02	0,04	0,075	0,18	0,27	0,49	0,28	0,25	0,08	0,069	0,04	0,03	0,02
eccentricity	60°	50°	40°	30°	20°	10°	—	10°	20°	30°	40°	50°	60°	70°

All these numbers refer to the horizontal meridian. The visual acuity in the diagonal meridians is poorer, as nearly as I could see from not very many observations. The vertical meridian is relatively poorest below the horizontal. The observation is very difficult here and scarcely possible beyond 40 degrees.

The study by Fick and Köster shows quite different results.(1) To be sure, their visual acuity for light adaptation is not significantly different. That for dark adaptation, in contrast, is quite different. It is almost constant at the periphery and is between 0.03 and 0.04. It is almost zero at the center. From this, Fick (2) developed the theory of rod and cone acuity, based on the deliberations of von Kries. But this experiment was done with the reading test method, the errors of which were adequately emphasized above. It was assumed that for this reason the visual acuity of my observers would be higher. The greater practice of my test subjects also helped. As for

(1) Fick. On rod and cone acuity. Gräfes Arch. B. 45. Köster, Zentralbl. f. Physiol., 1896.

(2) See Wundt. Physiological Psychology, 5th Ed., Vol II, p. 506, where the curve is presented.

the cone and rod acuity, I refer otherwise to Wundt's criticism in Physiological Physiology [1]. The result of my work, however, is a strong support for the objections expressed there.

Results of the Expanded Study / 291

a) Compensation of the brightness to subjective equality [2]. I undertook these studies jointly with Prof. Wirth. After all the previous results, both for periphery and center, with increasing eccentricity, had been obtained with objectively identical brightness, in which case the objects always became subjectively brighter, this overshoot was compensated here by an episkotister* in front of the pairs of lines. The individual differences between Prof. Wirth and Reiss were minimal, although the episkotister* was adjusted from 10 degrees laterally to about 130 degrees, and from 50 degrees to about 240 degrees. Here the visual acuity appeared as somewhat lower.

b) Effect of practice (Figure 5).

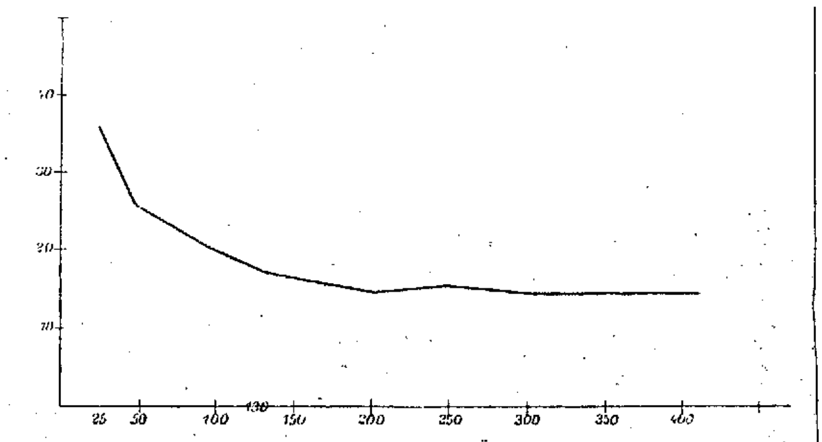

Figure 5. Effect of practice. Abscissa: ordinal number of the experiment. Ordinate: threshold in minutes. Observer: Reiss (10° temporal, left eye). Horizontal meridian.

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(1) 5th Edition, Vol. 2, p. 580.
(2) Only Bloom and Garten, in the study cited above, worked before me on this principle.

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*Translator's note: This is an unknown old German word.

Each series of experiments included 130 individual tests. Of these, the first thirty were excluded as adaptation experiments, and only the average of a hundred was taken. With two observers, I made some 130 tests at 10 degrees eccentricity. For Mr. Reiss the visual threshold was 36' after 25 tests. At the 130th test it sank to 17'30", and with 400 tests to 15'. The greatest practice was shown after 250 tests (100% improvement). Then it remained at the same level. / 292

c) Effect of fatigue. Figure 6, curve A, shows fatigue after $2\frac{1}{2}$ hours during dark adaptation. The first hour was not at all fatiguing. The second hour, in contrast, was considerably fatiguing. In the third hour, however, the test subject is no longer able to observe at all. On the other hand, curve B shows that fatigue proceeds quite differently with light

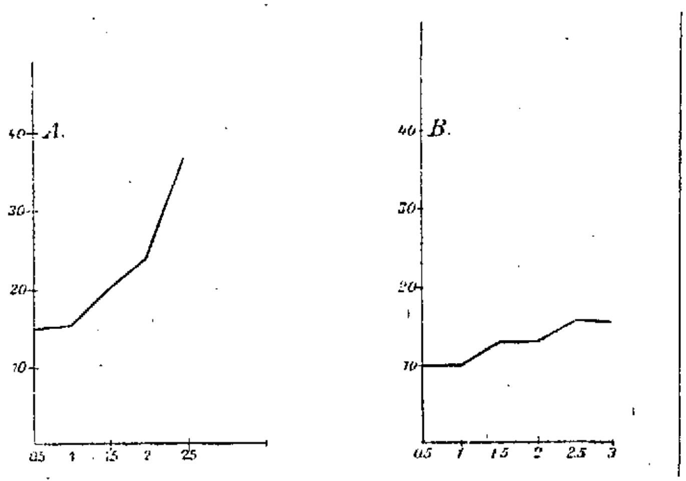

Figure 6. Effect of fatigue. Abscissa: duration of the tests in hours. Ordinate: threshold in minutes. Observer: Reiss (10° temporal, left eye). Horizontal meridian.

adaptation and is considerably less. Daylight is the most favorable for visual acuity as well as for the endurance.

In this sense, then, the light-adapted eye should not be called "fatigued", in contrast to the dark-adapted eye [(1)].

Summary

1) The visual acuity of the light-adapted eye is significantly greater than that of the dark-adapted eye, and the fatigue of the light-adapted eye is much less than that of the dark-adapted eye.

2) At the same subjective brightness, the visual acuity is reduced by a minimum in the periphery. /293

3) Under certain circumstances, practice can significantly improve the peripheral visual acuity.

4) The uncertainty judgements show a regular course similar to the one-ness and two-ness judgements.

5) The curve of the visual acuity shows a "zone of uncertainty, and its changes are proportional to the changes of the threshold itself.

6) These experiments have provided no proof for a specific cone or light acuity and rod or dark acuity.

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(1) Only in one pair of hours have I set up experiments on the smallest visual angle. They completely confirm Wülfing's observation. I reserve further studies in this direction for further work.

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